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AD NUMBER
AD078814
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Controlling DoD Organization: Army Biological Labs., Fort Detrick, Frederick, MD.
AUTHORITY
Dugway Proving Ground [Army] ltr dtd 10 Dec 1979; Dugway Proving Ground [Army] ltr dtd 10 Dec 1979

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INTERIM REPORT 100

PRINCIPLES AND PRACTICE OF BW DECONTAMINATION

22. Evaluation of Corps of Engineers Mobile Water Purification Unit for the Removal of B globigii Spores from Cold Water

By

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Work completed February 1955

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Published August 1955

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55AA 40058

CAMP DETRICK CONTROL NO. 55-MC- 1702

INTERIM REPORT 100

PRINCIPLES AND PRACTICE OF BW DECONTAMINATION

22. Evaluation of Corps of Engineers Mobile Water Purification Unit for the Removal of B globigii Spores from Cold Water

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PRINCIPLES AND PRACTICE OF BW DECONTAMINATION

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ACKNOWLEDGMENTS

Personnel of the Sanitary Engineering Branch, Corps of Engineers, Engineer Research and Development Laboratories, Fort Belvoir, Virginia, under the direction of Mr. Don C. Lindsten, Chief, Waste Disposal Section, operated the ERDL Mobile Water Purification Unit, provided laboratory facilities, and exhibited unlimited cooperation in all matters pertaining to the BW phase of this field test. Portions of the descriptive material and the two text figures were furnished by these Corps of Engineers personnel.

SUMMARY

A series of tests was performed to evaluate the use of the Corps of Engineers Research and Development Laboratories Mobile Water Purification Unit on cold water containing approximately 10^5 spores of B globigii per ml. The coagulation and filtration processes involved in the normal use of the unit did not produce safe water under these circumstances, nor did the normal chlorination procedure of 1 ppm improve the quality of the effluent water.

The recommended method of obtaining safe water when the water source is cold and contains a high concentration of resistant spores is to employ superchlorination to 100 ppm residual available chlorine at a pH lower than 7 (6.6) for 45 minutes. After this, the water is dechlorinated by addition of 600 ppm activated carbon, treated in the ERDL unit with coagulants, and filtered clear. This method appears to be practical and to produce potable water with safety.

Heating the water to 100°F before superchlorination, rather than reducing the pH, resulted in safe water but produced a contaminated sludge and, in addition, required special equipment.

INTERIM REPORT 100

PRINCIPLES AND PRACTICE OF BW DECONTAMINATION

22. Evaluation of Corps of Engineers Mobile Water Purification Unit for the Removal of B globigii Spores from Cold Water

I. INTRODUCTION

A. AUTHORIZATION

Letter TECRD MS 8-75-07-214 (8-75-05-014), dated 19 November 1954, subject "Field Test, Evaluation of Corps of Engineers Mobile Water Purification Unit for Removing Chemical and Simulated Biological Warfare Agents from Water," from Chief, Military Engineering Department, Corps of Engineers, US Army, Engineer Research and Development Laboratories, Fort Belvoir, Virginia, to Chief, Biological Laboratories, Camp Detrick, Frederick, Maryland, requested active participation in subject test in the form of two bacteriologists, a supply of B globigii spores, and the equipment and materials necessary for the bacteriologists to assay all biological samples. First Indorsement thereto, CMLCD-10-PD, dated 7 January 1955, from Assistant Chief Chemical Officer for BW, Camp Detrick, Frederick, Maryland, to Commanding Officer, Engineer Research and Development Laboratories, Fort Belvoir, Virginia, concurred with this request.

B. PURPOSE

A previous evaluation of the ERDL Mobile Water Purification Unit has been completed and presented in Camp Detrick Interim Report 66 (1)*. Briefly, the conclusions were as follows:

"1. Water contaminated with 10^4 to 10^7 vegetative cells of S marcescens per ml was sterilized when the unit was operated in the standard manner (coagulation, disinfection with 1 ppm available chlorine residual, and filtration).

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* See Bibliography

"2. Water contaminated with 10^5 B globigii spores per ml was not sterilized when the unit was operated in the standard manner even with chlorination up to 7.5 ppm.

"3. A definite and increasing BW hazard existed in sludge disposal when B globigii was the agent, even when the unit was operated with chlorination. When S marcescens was the agent used, a sludge hazard existed for at least 1 hour, even when the unit was operated with chlorination.

"4. A definite respiratory BW hazard existed within the unit."

As a result of the above findings, the Corps of Engineers decided to conduct further field tests in an effort to rid water of B globigii spores under cold-weather conditions by various pretreatment processes which consist of "superchlorination" and subsequent dechlorination, followed by treatment with the ERDL Mobile Water Purification Unit.

C. DESCRIPTION OF THE WATER PURIFICATION UNIT

A cut-away drawing of the unit is presented as Figure 1, and a complete description is contained in Reference (1). The unit (also called an ERDLator) is a solids contact clarifier arranged for continuous coagulation. A sketch of the unit (not to scale) is included as Figure 2. In operation, raw or pretreated water is admitted to the mixing zone, where it is thoroughly intermingled with the primary coagulant (ferric chloride) fed by a solution feeder, the coagulant aid (powdered limestone) fed by a slurry feeder, and, generally, with a disinfectant (calcium hypochlorite) fed by a solution feeder. This intermingling is accomplished by a series of belt-driven rotating discs. The intermingled water along with the developing ferric hydroxide floc passes upward through the multiple vanes into the clarification zone. As the water reaches the level above the slurry or sludge blanket, which is maintained by a continuous withdrawal of the excess slurry into the sludge concentrator, the upper effluent is relatively clear. The concentrated sludge of the concentrator is vented off to waste. The clear water of the separator zone is carried over to a holding tank or wet well along with the top clear portion of the concentration. From the wet well the effluent is pumped into a diatomite filter for further clarification.

Figure 1

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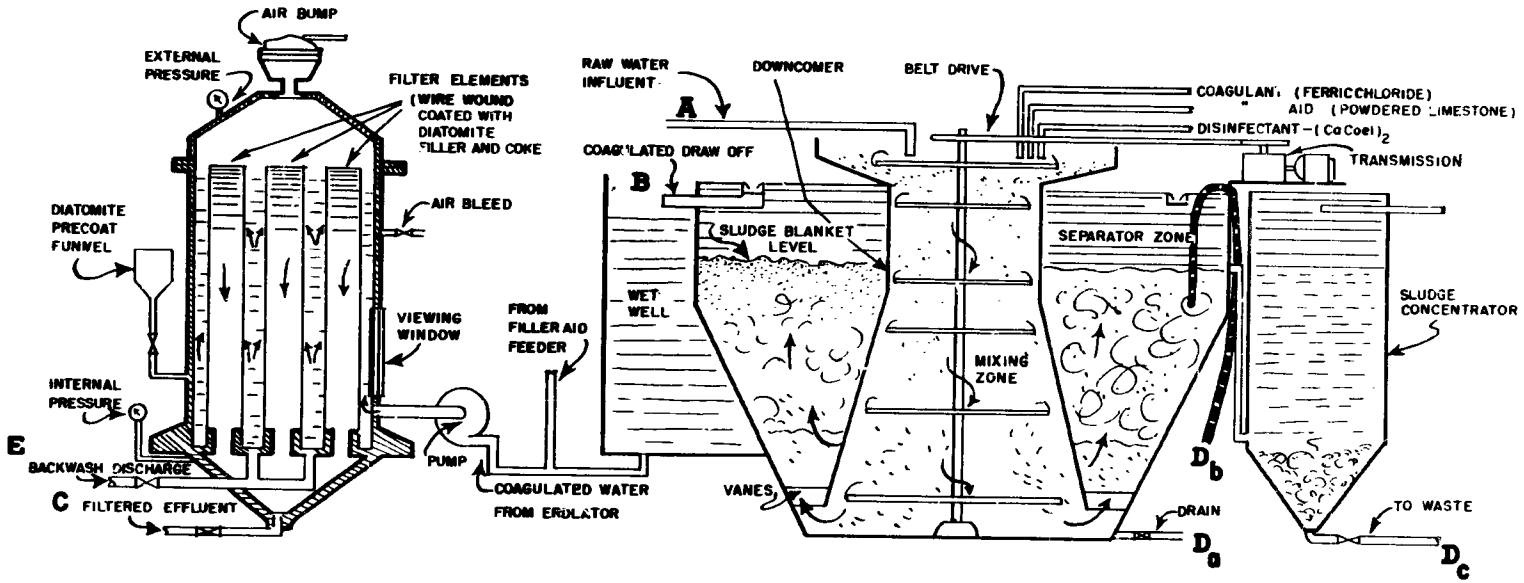

SKETCH (not to scale)

SAMPLING POINTS:

A. RAW **B.** COAGULATED **C.** FILTERED

D. SLUDGE (a) ERDLATOR DRAIN
(b) IN ERDLATOR BY SYPHON
(c) BOTTOM OF SLUDGE CONCENTRATOR

E. FILTER BACKWASH

FIG. 2 CROSS-SECTION OF DIATOMITE FILTER AND ERDLATOR SHOWING POINTS OF SAMPLING

A.P. HILL TESTS – B W FEB. 1955.

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The effluent of the ERDLator is pumped into the interior of the diatomite filter, having picked up a predetermined amount of filter aid which is deposited on the precoated diatomaceous earth cake held on the wire elements. Water passing through the cake to the interior of the elements is carried over to a clear well for distribution. The continuous addition of filter aid to the cake results in a slow pressure rise on the outside, and eventually the cake must be removed and replaced. The time for backwashing is determined by the differential of internal and external pressures on the elements, which indicate the density of cake impeding the output of filtered effluent. Removal of the cake is accomplished by using the impounded air in the upper portion of the filter on the air pump principle (i.e, a quick reduction of the external pressure) to literally blast the cake from the face of the elements and wash the expended filter aid to waste. By a reversal of the process, a new cake is developed by a precoat and a new cycle of filtering is begun.

D. PRELIMINARY TESTS

Upon being informed by the Corps of Engineers that pretreatment consisting of "superchlorination" of the contaminated water for 45 minutes would be employed in these trials, preliminary tests were conducted at Camp Detrick to determine the titratable residual chlorine required in the field.

A general formula for the sterilization of distilled water containing anthrax spores by hypochlorites has been derived by Fair and co-workers (2). The formula is:

$$R = 99 \frac{1.073^{(25-T)}\, N^{2/9}}{t^{3/2}} \left[1 + \frac{K}{(H_3O^+)}\right]$$

Here, R = required titratable residual chlorine in ppm
N = number of spores present per ml
T = temperature of water °C
t = time of contact, minutes
K = ionization constant of HOCl (varies with T; 2.0×10^{-8} at 0°C)
(H_3O^+) = hydrogen ion concentration

Since B globigii spores are as resistant as B anthracis, the above formula was used to calculate the amount of residual chlorine required to destroy 1×10^5 B globigii speres at pH 7 within 45 minutes at 0°C.

Laboratory tests were then performed and the applicability of the formula was confirmed. Between 75 and 100 ppm titratable residual chlorine would be required under the specified conditions.

E. TEST AGENT

A paste containing 2200 grams of B globigii spores (Camp Detrick Production Lot No. 112-BG-204) was suspended in 18 liters of sterile distilled water and the suspension was homogenized under aseptic conditions. The final bacteriological count was 2×10^{10} spores per ml. The spore suspension was kept at approximately 40°F by immersing the 5-gallon container of spores in a spring at the test site.

F. TEST SITE

The field trials were conducted at the edge of Miller's Pond, Camp A. P. Hill, Bowling Green, Virginia. All the raw water used during the trials was pumped from Miller's Pond.

II. TEST PROCEDURE

A. TESTS PERFORMED

Each of the following six tests was performed under conditions determined by Corps of Engineers personnel during the actual trials. After each test, the ERDL Mobile Water Purification Unit was decontaminated by pumping water containing 100 ppm chlorine and adjusted to pH 4 through the entire unit for at least 1 hour, followed by a thorough rinse with pond water.

1. Test No. 1

The effect of superchlorination (100 ppm titratable residual chlorine) on spores in cold water at three different pH values.

2. Test No. 2

Superchlorination (100 ppm) in cold water at a lowered pH, followed by:

a. Dechlorination with 600 ppm activated carbon.

b. Treatment with the ERDL Mobile Water Purification Unit operating under the following conditions:

(1) Coagulation. A coagulant bed was preformed by operating the unit for approximately 4 hours with pond water.

(2) No chlorination.

(3) Filtration. Standard "precoat" method, i.e, adding a diatomaceous earth slurry (0.1 lb/sq ft of filter area) directly to the filter elements.

3. Test No. 3

No superchlorination. Treatment with the ERDL Mobile Water Purification Unit operating under the following conditions:

a. Coagulation with no preformed coagulant bed.

b. Chlorination to approximately 1 ppm titratable residual chlorine.

c. Filtration. Standard precoat method.

4. Test No. 4

No superchlorination. Treatment with the ERDL Mobile Water Purification Unit operating under the following conditions:

a. Coagulation. A coagulant bed was preformed by operating the unit for approximately 4 hours with pond water.

b. No chlorination.

c. Filtration. Standard precoat method for the first 2½ hours of the run; "body-feed" method used for the last 3½ hours of the run. In the body-feed method, approximately 20 ppm of diatomaceous earth were added directly to the water entering the filter unit.

5. Test No. 5

No superchlorination. Treatment with the ERDL Mobile Water Purification Unit operating under the following conditions:

a. No coagulation.

b. Chlorination to approximately 1 ppm titratable residual chlorine.

c. Filtration. Standard precoat method for the first 3 hours of the run; a combination of the precoat and body-feed methods during the last 3 hours of the run.

6. Test No. 6

Superchlorination (100 ppm) with no adjustment of pH, but with the water heated to 100°F, followed by:

a. Dechlorination with 600 ppm activated carbon.

b. Treatment with the ERDL Mobile Water Purification Unit operating under the following conditions:

(1) Coagulation with no preformed coagulant bed.
(2) No chlorination.
(3) Filtration. A combination of the precoat and body-feed methods during the entire run.

B. SAMPLING

1. Chemical Samples

Samples of water for chemical analysis were collected in bottles other than those used for collecting the bacteriological samples. All chemical analyses were performed by Corps of Engineers personnel.

2. Bacteriological Samples

a. Samples for viable bacteria assay, when the ERDL Mobile Water Purification Unit was employed, were taken at the following five points (see Figure 2):

(1) Raw contaminated, at feed water rotameter inlet.
(2) Coagulated, at effluent trough overflow.
(3) Filtered, at hose discharging filtered water.
(4) Sludge, at sludge concentration waste outlet or from near the bottom of the coagulator.
(5) Filter bed backwash, at waste line.

Samples from the tanks where superchlorination was employed were taken at various intervals after the microorganisms and disinfectants were added.

b. All the sample bottles were sterile and contained 1 ml of sterile, aqueous 18 percent sodium thiosulfate to neutralize chlorine when present (1 ml of 18 percent sodium thiosulfate neutralizes more than 250 ml of H_2O containing 100 ppm Cl_2). Since the volume of every sample was at least 200 ml, the resulting concentration of sodium thiosulfate (less than 0.09 percent) is one known not to inhibit the growth of the test agent.

c. Samples of the filtered water and of water from tanks where superchlorination was employed were assayed by both the membrane (millipore) filter and pour plate methods. These samples were taken in sterile 250-ml ground-glass-top graduates. All other samples were assayed only by the pour plate method, and these samples were taken in sterile 8-oz screwcapped prescription bottles.

(1) Membrane Filter Method of Assay

Ringed Lovell Millipore Filters*, sterilized by exposure to the vapors of ethylene oxide, were used. Water samples of 50-, 60-, or 100-ml portions (limited to less than 100 ml in cases where unfiltered water samples, which clogged the MFs, were used) were filtered through each of two MFs held in the MF holders designed at Camp Detrick. After each filtration, the MFs held in the holders were rinsed once with 10 ml of sterile distilled water. MFs were placed in glass dishes on blotters containing 2 ml of trypticase soy broth**. The dishes were incubated at 37°C for 15 hours. The number of colonies appearing on the MFs was counted with a 9X stereoscopic microscope.

(2) Pour Plate Method of Assay

Five-ml pipettes were used to deliver 5.0 ml of the water samples to petri dishes. One-ml pipettes were used to make decimal serial dilutions in 9-ml sterile distilled water blanks and to deliver 1.0 ml of the dilutions in duplicate petri dishes. Nutrient agar*** was poured into the dishes and incubated at 37°C for 40 hours.

At the request of the Corps of Engineers, all samples were collected by Corps of Engineers personnel. Accordingly, instructions issued to these personnel emphasized the necessity of maintaining aseptic techniques while taking the samples for bacteriological assay.

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* Lovell Chemical Company, Watertown, Massachusetts.

** Baltimore Biological Laboratories, Baltimore, Maryland.

*** Camp Detrick Media Catalog Type 103.

III. INDIVIDUAL TESTS

A. TEST NO. 1

1. General

This test was designed to determine the effect of 100 ppm titratable residual chlorine ("superchlorination") on the spores of B globigii in cold water at three different pH's. The ERDL Mobile Water Purification Unit was not used in this test. Since it had been determined in previous Corps of Engineers trials that a concentration of 100 ppm chlorine is effective in the decontamination of water containing certain CW agents, this concentration was used for all superchlorination processes employed during this field trial.

2. Test Procedure

Each of three collapsible GRS-coated nylon water tanks (tanks No. 1, 2, and 3) was filled with 3,000 gallons of water from Miller's Pond, and 115 ml of the stock B globigii suspension of 2×10^{10} spores per ml were added to each tank. The organisms were mixed in the water for 5 minutes by means of canoe paddles and a pump which circulated water continuously at a rate of 55 gallons per minute. At this point samples were taken from each tank to determine the extent of spore contamination. A slurry of 3.6 lb "HTH" (70 percent calcium hypochlorite) was added to each tank, along with 2,200 ml of concentrated HCl in tank No. 1 and 1,350 ml of concentrated HCl in tank No. 2. No acid was added to the water in tank No. 3. The HTH and acid were mixed with the water for 5 minutes in the same manner in which the microorganisms were mixed. The water-circulating pumps were operated at each tank throughout the duration of the test. Samples of the water from each tank were taken at 0 time (after the 5-minute mixing period) and at the indicated intervals after 0 time.

3. Results

Chemical and bacteriological analyses of the water samples are presented in Tables I and II in the Appendix.

4. Conclusions

It is evident that a pH of 7 or lower is necessary to attain complete kill within 45 minutes of 1 to 2×10^5 spores per ml in cold water containing 100 ppm chlorine.

B. TEST NO. 2

1. General

This test was designed to determine the effect of superchlorination (100 ppm for 45 minutes at a low pH), dechlorination (with 600 ppm activated carbon), and treatment with the ERDL Mobile Water Purification Unit (operating with coagulation and a preformed bed, no chlorination, and filtration with the standard precoat method) on the spores in cold water.

2. Test Procedure

a. Superchlorination

Water tanks 2 and 4 were each filled with 3,000 gallons of water, and 115 ml of the stock spore suspension were added to each tank. After mixing in the manner described in Test 1, samples were taken from each tank. HTH (3.6 lb) and 2,000 ml of concentrated HCl were added to each tank and mixed in the manner previously described. Samples were taken at Ø time (after the 5-minute mixing period) and 0 plus 45 minutes.

b. Dechlorination

At the end of the 45-minute superchlorination period, the contents of tank No. 2 were pumped to tank No. 3, and the contents of tank No. 4 were pumped to tank No. 1. Water tanks 1 and 3 were empty except for 15 pounds of activated carbon. A water circulating pump was operating at each tank during the entire dechlorination process. As soon as tanks 1 and 3 were filled (approximately 1 hour), samples were taken.

c. Treatment with the ERDL Mobile Water Purification Unit

At the end of the dechlorination time (1 hour), the water was led from tanks 1 and 3 to the ERDL Mobile Water Purification Unit. Coagulated, filtered, and sludge water samples were taken after 1, 1½, 2½, and 3 hours' operation of the unit. The sludge samples were taken at the waste outlet of the sludge concentrator.

3. Results

Chemical and bacteriological analyses of the water samples are presented in Tables III and IV in the Appendix.

4. Conclusions

Water containing up to 2 x 10^5 B globigii spores per ml can be sterilized under the conditions of this test. It is of interest to note that the sludge samples contained many organisms other than B globigii. Since a bacteriological assay had shown that approximately 150 organisms (not B globigii) per ml were present in the water from Miller's Pond, and since no chlorine was used in the ERDL Mobile Water Purification Unit, it may be concluded that the sludge contained organisms as a result of the 4 hours' operation of the unit with the pond water to preform the coagulant bed. It is felt that the presence of a few B globigii colonies on the MFs or pour plates may result from chance contamination, rather than the actual presence of the spores in the water. Such contamination could occur in the laboratory where traffic was necessarily heavy, or in the field where the sample bottles were handled by personnel who worked near the contaminated water and where both the personnel and the sample bottles were exposed to any bacterial aerosol or spray resulting from the constant pumping, mixing, and treating of the test waters.

C. TEST NO. 3

1. General

This test was designed to determine the extent of removal of spores from cold water by means of the ERDL Mobile Water Purification Unit operating in the standard manner (coagulation with no preformed bed, chlorination to approximately 1 ppm, and filtration with the standard precoat method).

2. Test Procedure

A stock spore suspension of 19 ml was added to 500 gallons of pond water contained in a small tank. A water-circulating pump was operating at the small tank during this entire run. Pond water was pumped into the tank at the rate of 25 gallons per minute and water from the same tank was pumped simultaneously at the same rate into the ERDL Mobile Water Purification Unit. At the same time, a spore suspension, consisting of 345 ml of the stock suspension mixed with 30 gallons of water, was bled into the small tank at the rate of 5 gallons per hour by means of a Signamotor. Thus a constant flow of water, contaminated to approximately 1 x 10^5 spores per ml, was fed into the ERDL Mobile Water Purification Unit for 6 hours. Raw contaminated, coagulated, and filtered water samples were taken after ½, 1, 1½, 2, 3, 4, 5 and 6 hours' operation of the unit. No samples

were taken from the sludge concentrator, but at the end of 6 hours' operation a sample of sludge released from a waste line near the bottom of the coagulator was taken and assayed.

3. Results

Chemical and bacteriological analyses of the water samples are presented in Tables V and VI in the Appendix.

4. Conclusions

Complete sterilization of spore-contaminated water was not achieved under the conditions of this test. Significant reductions resulted: Coagulation alone caused a spore reduction of 27 to 97 percent, depending on time, while the combination of coagulation and filtration caused a reduction of 97.6 to 99.998 percent. Upon assay of the sludge sample removed from near the bottom of the coagulant bed, it was apparent that the low concentration of chlorine used in this test had no appreciable effect upon the spores and that a BW hazard exists in the waste products of the unit.

D. TEST NO. 4

1. General

This test was designed to determine the extent of mechanical removal of spores from cold water by means of the ERDL Mobile Water Purification Unit operating without chlorination (coagulation with a preformed bed and filtration with the precoat method for the first 2½ hours, and the body-feed method for the last 3½ hours of operation).

2. Test Procedure

Water was contaminated and led into the unit in the same manner as described in Test 3. Raw contaminated, coagulated, filtered and sludge water samples were taken at the indicated intervals during the operation of the unit. The sludge samples were siphoned from near the bottom of the coagulator with a long length of tygon tubing. The tubing was flushed for at least 30 seconds just before taking each sludge sample. This method was used, rather than drawing the sludge from the bottom of the coagulator through the waste line, to prevent "breaking" the coagulant bed. In the course of operating the unit, it was necessary to backwash the filter bed (diatomaceous earth and floc) from the filter elements when the filter clogged to the point where the proper flow of water was inhibited. After 5 hours' operation in this test, a sample of the filter bed backwash was taken at the waste line.

3. Results

Chemical and bacteriological analyses of the water samples are presented in Tables VII and VIII in the Appendix.

4. Conclusions

It is evident that the spores were not removed completely under the conditions of this test. Significant reduction resulted: Coagulation caused a bacterial reduction of 94 to 98 percent, while the combination of coagulation and filtration caused a reduction of 98 to 99.999 percent. Analysis of the sludge samples and the filter bed backwash sample showed that a BW hazard exists in the waste products of the unit.

E. TEST NO. 5

1. General

This test was designed to determine the effect on spores in cold water when treated with the ERDL Mobile Water Purification Unit employing the method used to treat non-turbid waters (no coagulation, chlorination to approximately 1 ppm, and filtration with the precoat method for the first 3 hours, and a combination of the precoat and body-feed methods for the last 3 hours of operation).

2. Test Procedure

Water was contaminated and led into the unit in the same manner as in Tests 3 and 4. Raw contaminated, coagulated, and filtered water samples were taken at the indicated intervals. Since there was no coagulation process in this run, no sludge samples were taken. Water samples were taken at point (2) (see page 8) to determine the effect of the chlorine (minus the effect of filtration) on the spores. Filter bed backwash samples were taken after 2½, 5 and 6 hours' operation of the unit.

3. Results

Chemical and bacteriological analyses are presented in Tables IX and X in the Appendix.

4. Conclusions

Little, if any, reduction in spore count resulted under the conditions of this test. It is evident that the low concentration of chlorine had no effect on the test agent in cold water. The filter bed backwash samples indicated that spores were entrapped and might constitute a BW hazard in the waste products of the unit.

F. TEST NO. 6

1. General

This test was designed to determine the effect of superchlorination in water at 100°F with no adjustment of pH (100 ppm chlorine for 45 minutes), dechlorination (with 600 ppm activated carbon), and treatment with the ERDL Mobile Water Purification Unit (operating with coagulation and no preformed bed, no chlorination, and filtration with a combination of the precoat and body-feed methods) on the spores in water. This method was evaluated because of a possible future need for the Corps of Engineers to develop means of supplying warm water in the field.

2. Test Procedure

a. Superchlorination

Water tanks 1 and 4 were each filled with 3,000 gallons of water heated to approximately 100°F by means of a "Cyclotherm" heater. After adding and mixing 115 ml of the stock spore suspension to each tank in the manner previously described, samples were taken from each tank. Added and mixed in each tank were 3.6 lb of HTH (no HCl was added), and samples were taken at 0 time (after the 5-minute mixing period) and at the indicated intervals after 0 time.

b. Dechlorination

Dechlorination with 600 ppm activated carbon proceeded in tanks 2 and 3 in the manner previously described (the contents of tank 1 were pumped into tank 2, and the contents of tank 4 were pumped into tank 3). Samples of the dechlorinated water in each tank were taken just prior to being led into the ERDL Mobile Water Purification Unit.

c. Treatment with the ERDL Mobile Water Purification Unit

At the end of the dechlorination time (approximately 1 hour), the water was led from tanks 2 and 3 to the unit. Coagulated, filtered, and sludge water samples were taken after 3/4, 1 3/4, 2 3/4, and 3 3/4 hours' operation of the unit. The sludge samples were siphoned from near the bottom of the coagulator in the manner previously described. Filter bed backwash samples were taken after 1 3/4 and 3 3/4 hours' operation of the unit.

3. Results

Chemical and bacteriological analyses are presented in Tables XI and XII in the Appendix.

4. Conclusions

It is possible to sterilize spore-contaminated water under the conditions of this test. As indicated by the sludge and filter-bed backwash samples, superchlorination alone for 45 minutes with 100 ppm Cl_2 at 100°F with no adjustment of pH does not destroy all of the 2×10^5 spores per ml in water; therefore, coagulation and filtration are necessary to remove mechanically the relatively few remaining viable spores. However, under these circumstances a BW hazard exists in the waste products of the unit.

IV. CONCLUSIONS

Replicate tests were not performed in this series, so that the absolute significance of some of the data cannot be estimated. For this same reason, and because operating conditions were changed frequently within a single test, it is not possible to compare the efficiency of various combinations of operating procedures nor to recommend a single best method of operating the ERDL unit without superchlorination. It may, however, be concluded that superchlorination (to 100 ppm) of water at 0°C for 45 minutes is ineffective in removing *B globigii* spores (10^5 per ml) from water if the pH is not adjusted. However, if the pH is adjusted to 6.6 or lower and the ERDL unit is used to remove the carbon needed for dechlorination, the water is rendered safe for drinking. Heating the water to 100°F and treating it with 100 ppm available chlorine for 45 minutes without pH adjustment was found to give as good an effluent as water superchlorinated at 0°C at a pH of 6.6. However, the sludge was found to be highly contaminated, indicating a lesser effect of chlorine. In view of the greater simplicity and economy involved

in employing a small amount of acid rather than a large piece of water-heating equipment, the pH adjustment method is certainly to be preferred. When no superchlorination was used, the various stages of the ERDL Mobile Water Purification Unit could be evaluated. Coagulation reduced the concentration from 2 x 10^5 to approximately 10^4; this process alone, therefore, is useless. When both coagulation and filtration were employed, the reduction was much greater. Since tests showed that filtration alone was ineffective, it is evident that the filter removes organisms which are physically trapped in the floc formed by the coagulants. However, the water resulting from the combination of coagulation and filtration processes was variable in quality and had an average of 10^2 spores per ml, which is considered unsafe, and the sludge and filter cake were highly contaminated. As might be expected, a residual available chlorine concentration of 1 ppm had no effect on the spores and did not affect the filterability of the coagulum.

It is concluded that for cold water containing approximately 10^5 spores per ml, the following prodedure should be employed: Superchlorination at 100 ppm residual available chlorine at a pH lower than 7 for 45 minutes, followed by dechlorination (by addition of 600 ppm activated carbon), and coagulation and filtration in the ERDL Mobile Water Purification Unit.

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APPENDIX

Tables of Data

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TABLE I. CHEMICAL AND ANALYTICAL DATA, TEST NO. I

Water Sample	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ Hardness (ppm) Ca^{++}	$CaCO_3$ Hardness (ppm) Total	Temp. (°F) H_2O	Temp. (°F) Air	pH	Turbidity (ppm)	Color (ppm)	Total Cl_2 (ppm)
Pond	0	10.0	31	38	35		7.6	?.0	50	0
Pond	0	6.0	16	22	37	31	5.9	3.0	40	0
Tank 1, H_2O + Bg	0	14.0	12	22			7.4	4.0	40	0
Tank 1, H_2O + Bg + HTH + acid, 0 time			108	110			3.45	4.0	30	111.0
Tank 1, " " " " 0 time	0	8.0	108	108			3.5	3.5	30	110.2
Tank 2, " " " " 0 time	0	26	112	122			6.15	3.0	40	109.5
Tank 2, " " " " 0 + 15 min	0	22.0	113	124			6.55	4.0	30	108.0
Tank 2, " " " " 0 + 30 min	0	24			37	28	6.6	5.0	30	108.9
Tank 2, " " " " 0 + 1 hr	0	20.0	116	126			6.65	5.0	30	108.2
Tank 3, " " " , 0 time.	0	40.0	102	106			8.6	3.0	50	94.1
Tank 3, " " " 0 + 30 min	0	44.0	108	108	36		9.15	3.0	50	130.6
Tank 3, " " " 0 + 1 hr	0	74.0	104	106			9.1	3.0	50	109.9
Tank 3, " " " 0 + 1½ hr	0	64.0	104	104			9.0	3.0	50	109.1
Tank 3, " " " 0 + 2 hrs	0	64.0	105	106	36		9.15	3.0	50	107.2

* Phenolphthalein
** Methyl orange

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TABLE II. VIABLE BACTERIA COUNT, TEST NO. 1

Sample	MF* Bg/ml	PP** Bg/ml
Pond H_2O	-	0(150 microorg. other than Bg)
Tank 1, after contamination	-	2×10^5
Tank 1, " " + HTH + acid, 0 time	120	3.4×10^3
Tank 1, " " " " 0 + 15 min	0.15	0
Tank 1, " " " " 0 + 30 min	0.14	0.1
Tank 1, " " " " 0 + 45 min	0.14	0.1
Tank 2, after contamination	-	1.4×10^5
Tank 2, " " + HTH + acid 0 time	268	540
Tank 2, " " " " 0 + 15 min	4.7	4.4
Tank 2, " " " " 0 + 30 min	0.85	0.4
Tank 2, " " " " 0 + 45 min	0.3	0.1
Tank 2, " " " " 0 + 1 hr	0.1	0.1
Tank 3, after contamination	-	2×10^5
Tank 3, " " + HTH 0 time	TNTC***	1.9×10^5
Tank 3, " " " 0 + 15 min	TNTC	1.7×10^5
Tank 3, " " " 0 + 30 min	TNTC	1.9×10^5
Tank 3, " " " 0 + 45 min	TNTC	1.4×10^5
Tank 3, " " " 0 + 1 hr	TNTC	1.2×10^5
Tank 3, " " " 0 + 1½ hr	TNTC	9×10^4
Tank 3, " " " 0 + 2 hrs	TNTC	9×10^4

* Millipore filter
** Pour plate
*** Too numerous to count

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TABLE III. CHEMICAL AND ANALYTICAL DATA, TEST NO. 2

Water Sample	Time (hr)	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ Hardness (ppm) Ca^{++}	$CaCO_3$ Hardness (ppm) Total	Temp (°F) H_2O	Temp (°F) Air	pH	Turbidity (ppm)	Color (ppm)	Total Cl_2 (ppm)
Pond		0	12	12	16	34	18	6.9	5.0	40	0
Tank 2, after contamination		0	12	8	12	34	22	6.95	5.0	40	0
Tank 2, after contam. + HTH + acid, 0 + 45 min		0	19.8#	108	110	-	-	3.7	4.0	40	118.5
Tank 3, after dechlor. of tank 2		0	57.6#	108	108	-	-	2.9	-	-	0
Tank 4, after contamination		0	12	14	18	34	-	7.15	5.0	40	0
Tank 4, after contam. + HTH + acid, 0 + 45 min		0	45.9#	116	116	-	24	3.75	4.0	40	113.6
Tank 1, after dechlor. of tank 4		0	57.6#	108	108	-	-	2.9	-	-	0
Coagulated	1	0	20	216	220	-	-	5.9	5.0	5.0	0
Filtered	1	0	20	-	-	35	34	5.65	0	<5	0
Coagulated	1½	0	20	-	-	-	-	6.1	6.0	5.0	<0.1
Filtered	1½	0	20	217	222	-	-	6.1	0	<5	<0.1
Coagulated	2¼	0	22	-	-	-	-	6.1	10	10	0
Filtered	2¼	0	21	232	240	34	34	6.15	<0.1	5	0
Coagulated	3	0	22	-	-	-	-	6.1	10	8	0
Filtered	3	0	24	236	242	34	33	6.15	<0.1	5	0

*Phenolphthalein
**Methyl orange
Acidity

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TABLE IV. VIABLE BACTERIA COUNT, TEST NO. 2

Sample	Time (hr)	MF* Bg/ml	PP** Bg/ml
Tank 2, after contamination		-	1.8×10^5
Tank 2, after contam. + HTH + acid, 0 + 45 min		0.66	0
Tank 3, after dechl. of contents of tank 2		-	0.2
Tank 4, after contamination		-	2×10^5
Tank 4, after contam. + HTH + acid, 0 + 45 min		0.14	0.2
Tank 1, after dechl. of contents of tank 2		-	0.2
Coagulated	1	-	0
Sludge	1	-	0 (600 microorg. other than Bg)
Filtered	1	0.01	0
Coagulated	1½	-	0
Sludge	1½	-	0 (600 microorg. other than Bg)
Filtered	1½	0.1	0
Coagulated	2¼	-	0.2
Sludge	2¼	-	0 (200 microorg. other than Bg)
Filtered	2¼	0.5	0.4
Coagulated	3	-	0
Sludge	3	-	0 (150 microorg. other than Bg)
Filtered	3	0.08	0

* Millipore filter

** Pour Plate

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TABLE V. CHEMICAL AND ANALYTICAL DATA, TEST NO. 3

Note: Free available Cl_2 measured with orthotoluidine by color disc method.
Total available and combined Cl_2 measured by thiosulfate-iodine titer.
(difference = combined chlorine or chloramines)

Water Sample	Time (hr)	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ Hardness (ppm) Ca^{++}	$CaCO_3$ Hardness (ppm) Total	Temp (°F) H_2O	Temp (°F) Air	pH	Turbidity (ppm)	Color (ppm)	Cl_2 (ppm) Total	Cl_2 (ppm) Free
Pond		0	8.0	30	36	37	43	6.5	5.0	40	0	0
Coagulated	½	0	14.0	122	130	-	-	6.1	15.0	120	1.21	0.5
Coagulated	1	0	12.0	-	-	-	-	6.4	10.0	100	.5	>2.0
Filtered	1	0	13	256	274	37	47	6.45	<0.1	<5	3.2	>2.0
Coagulated	1½	0	12	-	-	-	-	6.4	10.0	100	-	-
Filtered	1½	0	12	256	276	37	46	6.4	<0.1	<5	5.5	>2.0
Coagulated	2	0	21	-	-	-	-	6.7	-	70	-	-
Filtered	2	0	22	218	256	-	-	6.75	<0.1	<5	4.51	>2.0
Coagulated	2½	0	12	-	-	-	-	6.85	4.0	60	-	-
Filtered	2½	0	12	94	108	40	52	6.85	0.2	<5	0.35	0.1
Coagulated	3	0	13	-	-	-	-	6.8	4.0	60	-	-
Filtered	3	0	12	98	110	40	60	6.8	0.1	<5	0.26	<0.1
Coagulated	4	0	16	-	-	49	59	7.15	2.0	40	1.49	1.0
Filtered	4	0	17	90	112	-	-	7.2	<0.1	<5	-	-
Coagulated	5	0	17	-	-	-	-	7.0	2.0	30	-	-
Filtered	5	0	18	130	142	40	59	7.0	<0.1	<5	1.28	1.0
Coagulated	6	0	20	-	-	-	-	7.1	1.5	30	-	-
Filtered	6	0	20	156	160	40	59	7.15	0.1	<5	3.05	2.0

*Phenolphthalein
**Methyl orange

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TABLE VI. VIABLE BACTERIA COUNT, TEST NO. 3

Water Sample	Time (hr)	MF* Bg/ml	PP** Bg/ml
Raw contaminated	½	-	1.5×10^5
Coagulated	½	-	1.1×10^5
Raw contaminated	1	-	1.6×10^5
Coagulated	1	-	7.5×10^4
Filtered	1	7	14
Raw contaminated	1½	-	1.6×10^5
Coagulated	1½	-	2.2×10^4
Filtered	1½	3	10
Raw contaminated	2	-	1.5×10^5
Coagulated	2	-	1.2×10^4
Filtered	2	3	3
Raw contaminated	2½	-	1.5×10^5
Coagulated	2½	-	1.6×10^4
Filtered	2½	2×10^3	3.7×10^3
Raw contaminated	3	-	1.5×10^5
Coagulated	3	-	1.2×10^4
Filtered	3	Approx 100	80
Raw contaminated	4	-	1.1×10^5
Coagulated	4	-	7.3×10^4
Filtered	4	Approx 200	160
Raw contaminated	5	-	1.3×10^5
Coagulated	5	-	4.6×10^3
Filtered	5	4	4
Raw contaminated	6	-	1.7×10^5
Coagulated	6	-	4.7×10^3
Filtered	6	8	16
Sludge	6	-	5×10^6

* Millipore filter

** Pour plate

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TABLE VII. CHEMICAL AND ANALYTICAL DATA, TEST NO. 4

Water Sample	Time (hr)	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ ness Ca^{++}	Hard- (ppm) Total	Temp (°F) H_2O	Temp (°F) Air	pH	Tur- bidity (ppm)	Color (ppm)	Cl_2 (ppm) Total	Cl_2 (ppm) Free
Pond		0	11.0	12	14	34	13	6.4	3.0	35	0	0
Coagulated	½	0	28.0	-	-	-	-	6.9	2.0	30	0	0
Filtered	½	0	28.0	42	46	35	20	6.9	0.1	<5	0	00
Coagulated	1	0	31	-	-	-	-	6.95	3.0	30	0	0
Filtered	1	0	32	50	56	-	-	6.95	0.5	<5	0	0
Coagulated	1½	0	32	-	-	-	-	7.15	2.0	30	0	0
Filtered	1½	0	32	44	44	-	-	7.2	<0.1	<5	0	0
Coagulated	2	0	33	-	-	-	-	7.1	1.0	25	0	0
Filtered	2	0	34	46	48	36	23	7.1	<0.1	<5	0	0
Coagulated	2½	0	36	-	-	-	-	7.0	0.5	20	0	00
Filtered	2½	0	36	46	48	36	23	7.15	0.1	<5	0	0
Coagulated	3	0	32	-	-	-	-	7.2	1.0	20	0	0
Filtered	3	0	32	46	54	-	-	7.2	0.2	<5	0	0
Coagulated	4	0	38	-	-	-	-	7.4	1.0	15	0	0
Filtered	4	0	40	-	-	-	-	7.2	0.1	<5	0	0
Coagulated	5	0	36	-	-	-	-	7.7	0.7	15	0	0
Filtered	5	0	38	46	48	36	25	7.4	<0.1	<5	0	0
Coagulated	6	0	37	-	-	-	-	7.7	1.0	15	0	0
Filtered	6	0	38	48	50	38	25	7.6	<0.1	<5	0	0

*Phenolphthalein
**Methyl orange

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TABLE VIII. VIABLE BACTERIA COUNT, TEST NO. 4

Water Sample	Time (hr)	MF* Bg/ml	PP** Bg/ml
Raw Contaminated	½	-	2.2×10^5
Coagulated	½	-	1×10^4
Filtered	½	TNTC***	3.5×10^2
Raw Contaminated	1	-	2.1×10^5
Coagulated	1	-	9×10^3
Filtered	1	TNTC	3.25×10^3
Raw Contaminated	1½	-	2.3×10^5
Coagulated	1½	-	8.8×10^3
Sludge	1½	-	2.75×10^6
Filtered	1½	Approx 30	67
Raw Contaminated	2	-	1.8×10^5
Coagulated	2	-	9×10^3
Sludge	2	-	4.6×10^6
Filtered	2	TNTC	1.42×10^3
Raw Contaminated	2½	-	1.7×10^5
Coagulated	2½	-	9.9×10^3
Sludge	2½	-	5.6×10^6
Filtered	2½	TNTC	1.18×10^3
Raw Contaminated	3	-	1.4×10^5
Coagulated	3	-	6×10^3
Sludge	3	-	6.7×10^6
Filtered	3	Approx 9	17
Raw Contaminated	4	-	1.5×10^5
Coagulated	4	-	4.6×10^3
Sludge	4	-	7×10^6
Filtered	4	Approx 60	1.7×10^2
Raw Contaminated	5	-	1.4×10^5
Coagulated	5	-	3.2×10^3
Sludge	5	-	7×10^6
Filtered backwash	5	-	2.7×10^6
Filtered	5	2	2
Raw [illegible]ated	6	-	1.4×10^5
Coagulated	6	-	3.7×10^3
Sludge	6	-	8×10^6
Filtered	6	5	11

*Millipore filter
**Pour plate
***Too numerous to count

TABLE IX. CHEMICAL AND ANALYTICAL DATA, TEST NO. 5

Water Sample	Time (hr)	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ ness Ca^{++}	Hard- (ppm) Total	Temp (°F) H_2O	Temp (°F) Air	pH	Tur- bidity (ppm)	Color (ppm)	Cl_2 (ppm) Total	Cl_2 (ppm) Free
Pond		0	11.0	10	12	38	38	7.1	5.0	35	-	-
Coagulated	½	0	24	12	16	-	-	7.3	5.0	40	2.9	>2
Coagulated	1	0	20	-	-	-	-	7.15	5.0	35	-	-
Filtered	1	0	10	13	16	38	47	7.3	4.0	30	2.21	2.0
Coagulated	1½	0	19.0	-	-	-	-	6.95	4.0	35	2.27	2.0
Filtered	1½	0	18.0	12	16	38	47	6.9	3.0	35	2.27	2.0
Coagulated	2	0	16.0	-	-	-	-	6.6	4.0	30	-	-
Filtered	2	0	16.0	12	14	-	-	6.65	3.0	30	1.71	1.4
Coagulated	2½	0	16.0	-	-	-		6.7	4.0	30	-	-
Filtered	2½	0	15.0	11	14	-	-	6.75	3.0	30	1.68	1.4
Coagulated	3	0	15.0	-	-	-	-	6.8	4.0	30	-	-
Filtered	3	0	14.0	10	12	38	50	6.8	3.0	30	1.63	1.4
Coagulated	4	0	11.0	-	-	-	-	6.8	4.0	30	-	-
Filtered	4	0	10.0	10	12	38	50	6.95	3.0	30	1.77	1.4
Coagulated	5	0	12.0	-	-	-	-	6.8	4.0	30	-	-
Filtered	5	0	12.0	10	12	-	51.5	6.95	2.0	30	1.63	1.4
Coagulated	6	0	11.0	-	-	-	-	6.8	4.0	30	-	-
Filtered	6	0	11.0	10	12	38	49.5	6.9	1.5	30	1.2	1.0

*Phenolphthalein
**Methyl orange

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TABLE X. VIABLE BACTERIA COUNT, TEST NO. 5

Water Sample	Time (hr)	MF* Bg/ml	PP** Bg/ml
Raw contaminated	½	-	2.1×10^5
Coagulated	½	-	2×10^5
Raw contaminated	1	-	213×10^5
Coagulated	1	-	1.8×10^5
Filtered	1	TNTC***	1.6×10^5
Raw contaminated	1½	-	1.8×10^5
Coagulated	1½	-	1.8×10^5
Filtered	1½	TNTC	Approx 1×10^5
Raw contaminated	2	-	1.7×10^5
Coagulated	2	-	1.8×10^5
Filtered	2	TNTC	Approx 1×10^5
Raw contaminated	2½	-	1.5×10^5
Coagulated	2½	-	1.7×10^5
Filter bed backwash	2½	-	3×10^6
Filtered	2½	TNTC	Approx 1×10^5
Raw contaminated	3	-	1.8×10^5
Coagulated	3	-	1.5×10^5
Filtered	3	TNTC	Approx 1×10^5
Raw contaminated	4	-	1.5×10^5
Coagulated	4	-	1.4×10^5
Filtered	4	TNTC	Approx 1×10^5
Raw contaminated	5	-	1.5×10^5
Coagulated	5	-	1.2×10^5
Filter bed backwash	5	-	9.7×10^5
Filtered	5	TNTC	Approx 1×10^5
Raw contaminated	6	-	1.5×10^5
Coagulated	6	-	1.3×10^5
Filter bed backwash	6	-	3.7×10^5
Filtered	6	TNTC	Approx 7×10^4

* Millipore filter
** Pour plate
***Too numerous to count

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TABLE XI. CHEMICAL AND ANALYTICAL DATA, TEST NO. 6

Water Sample	Time (hr)	Alkalinity (ppm) Phen*	Alkalinity (ppm) M.O.**	$CaCO_3$ Hardness (ppm) Ca^{++}	$CaCO_3$ Hardness (ppm) Total	Temp (°F) H_2O	Temp (°F) Air	pH	Turbidity (ppm)	Color (ppm)	Total Cl_2 (ppm)
Pond		0	10.0	8.0	12.0	39	25	6.3	5.0	40	0
Tank 4, after contamination		0	14.0	10.0	13.0	97	37	6.7	5.0	40	0
Tank 4, after contam. + HTH, 0 time		24	114	48	96	-	-	9.3	5.0	40	117
Tank 4, " " " 0 + 15 min		24	140	96	114	-	39	9.4	5.0	40	116.0
Tank 4, after contam. + HTH, 0 + 45 min		53	104	96	115	97	41	9.4	5.0	40	106.1
Tank 3, after dechlor. of tank 4		0	28	94	100	93.5	45	7.2	-	-	0
Tank 1, after contamination		0	16.0	12.0	16.0	101	44	7.4	5.0	40	0
Tank 1, after contam. + HTH, 0 time		16	50	96	104	-	-	9.4	5.0	40	117.4
Tank 1, after contam. + HTH, 0 + 15 min		56	105	116	116	100	46	9.45	5.0	40	105.9
Tank 1, " " " 0 + 45 min		24	65	108	116	-	-	9.35	5.0	40	115.0
Tank 2, after dechlor. of tank 1		0	36	110	112	96	48.5	7.0	-	-	0
Coagulated	0	0	0	180	-	-	-	4.4	-	-	0
"	1	0	32	-	-	90	48.5	6.8	1.0	5.0	0
Filtered	1	0	31	116	124	-	-	8.9	<0.1	<5	0
Coagulated	2	0	36	-	-	-	-	7.1	6.0	<5	0
Filtered	2	0	36	128	140	94	48.5	7.05	0.3	<5	0
Coagulated	3	0	36	-	-	-	-	7.1	2.0	<5	0
Filtered	3	0	37	132	134	94	47.5	7.2	0.1	<5	0
		0									0
		0									0

*Phenolphthalein
**Methyl orange

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TABLE XII. VIABLE BACTERIA COUNT, TEST NO. 6

Water Sample		MF* Bg/ml	PP** Bg/ml
Pond		-	0.1 (270 microorg. other than Bg)
Tank 4, after contamination		-	1.97×10^5
Tank 4, after contam. + HTH,	0 time	TNTC***	1.85×10^5
Tank 4, " " "	0 + 15 min	Approx 64	1.17×10^3
Tank 4, " " "	0 + 30 min	2.5	23
Tank 4, " " "	0 + 45 min	TNTC	1.17×10^3
Tank 5, after dechlor. of tank 4		-	1
Tank 1, after contamination		-	2×10^5
Tank 1, after contam. + HTH,	0 time	TNTC	2.05×10^5
Tank 1, " " "	0 + 15 min	TNTC	1.96×10^3
Tank 1, " " "	0 + 30 min	TNTC	1.71×10^3
Tank 1, " " "	0 + 45 min	3.0	5
Tank 2, after dechlor. of tank 1		-	0.5
	Time (hr)		
Coagulated	3/4	-	1.8
Sludge	3/4	-	3
Coagulated	1 3/4	-	0
Sludge	1 3/4	-	30
Filter bed backwash	1 3/4	-	1.06×10^5
Filtered	1 3/4	0.2	0.3
Coagulated	2 3/4	-	0.1
Sludge	2 3/4	-	15
Filtered	2 3/4	0.16	0.2
Coagulated	3 3/4	-	0
Sludge	3 3/4	-	45
Filter bed backwash	3 3/4	-	4.9×10^3
Filtered	3 3/4	0.33	0.2

* Millipore Filter
** Pour plate
*** Too numerous to count

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75	Federal Civil Defense Administration Room 3449 Department of Health, Education and Welfare, North Washington 25, D.C. ATTN: Mr. James Cribbet
76	Executive Director Operations Research Office Johns Hopkins University 6410 Connecticut Avenue Chevy Chase, Maryland
77	Assistant Secretary of Defense (R&D) Room 3E 1025, The Pentagon Washington 25, D.C. ATTN: Executive Secretary BW-CW Coordinating Committee
78	Weapons Systems Evaluation Group Office of the Secretary Washington 25, D.C. ATTN: Dr. G. I. Walch
79 - 83	Commanding Officer Corps of Engineers, U.S.Army Engineer Research and Development Labs Fort Belvoir, Va.
84	Chief, Bureau of Yards and Docks Department of the Navy Washington 25, D.C.
85	Chief, Bureau of Medicine and Surgery Department of the Navy Washington 25, D.C. ATTN: Director, Special Weapons Division

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